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A.2. Measurement of Image Quality by Comparison.

Discussion

As the result of a search for a rapid and convenient method of evaluating image quality, it is suggested that a series of images of known quality be prepared which could be compared by eye with images where quality is to be determined. The quality of the image is dependent on several attributes of the image and, in some cases, on the use to be made of the image. For the purpose of gathering intelligence by photographic reconnaissance, the dependence on use may be removed by making the comparison between images of scenes of approximately the same type of subject material. Some variation of suitable material may well prove advantageous in order that image quality may be evaluated when only a limited variety of subject is available in the scene. It may well be that a synthetic scene made up of various geometric shapes and contrasts would provide a more suitable basis of comparison than any natural scene. Another alternative which should be the subject of eventual investigation is the use of a comparison scene generated by the combination of many parts of natural scenes containing a considerable variety of material.

and this should be studied as a part of the containing program

Those attributes of quality which it would be desirable to simulate are:

1) Information Content.

Here information is used in its generalized meaning having to do with the spatial frequencies present in the image. Such comparison scenes could be prepared from a single original by successive degradation of quality in known steps. It has been practical in the case of t

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Approved For Release 2005/12/23 : CIA-RDP79B00314A000500040005-8

Approved For Release 2005/12/23 : CIA-RDP79B00314A000500040005-8

comparison scenes prepared [redacted] to provide this degradation in quality by changing the focus of the copying camera by various amounts. The resolution of the degraded copies has been judged from three-bar targets imaged with the scene. An alternate method used by [redacted] to prepare comparison scenes has been to make nearly contact prints in which the separation of the light source provides a pre-selected transfer function between original and print. There is a well-known effect in the variation of image quality due to a variation in the shape of the transfer function even though the limiting resolution may be held constant. This effect has been discussed by [redacted] In the case of the camera system under discussion, one of the causes of loss of resolution may be image defects of the sort resulting from a focal shift or from random motion rather than small angle scatter such as high order spherical aberration or the effect of obscuration which has little effect on limiting resolution but reduces the contrast at lower frequencies.

The question of the size of resolution steps between samples best suited for comparison has been considered. The samples presently at hand were prepared with the aim of obtaining a $\sqrt{2}$ change in limiting resolution between each step.

(1) Ap.Optics, Vol 3, 1, 1964

Approved For Release 2005/12/23 : CIA-RDP79B00314A000500040005-8

Approved For Release 2005/12/23 : CIA-RDP79B00314A000500040005-8

The observers who have used these samples agree that smaller steps should be used in the next set to be prepared and $\sqrt{2}$ has been suggested.

2) Contrast Range.

The apparent quality of an image of a scene is affected by the contrast of the image. In order to make the selection of a comparison scene of the same image quality as that of the sample in an information content sense as accurate as possible, other variations between the two must be matched as well. One of these is contrast, the range of brightness variation. It has not been established just how well this quality need be matched for optimum accuracy but the two grades of contrast available in the [redacted] samples are felt to be too few. The next set should have three or perhaps four such steps.

Since natural effects, haze, high thin clouds and natural variations of terrain as well as defects such as corona, light leaks, improper exposure or processing all reduce contrast, the grading of results on the basis of this variable alone is expected to yield useful information.

3) Graininess.

The resolution of an optimized photographic system is often limited by the grain of the sensitive material. The appearance and thus the quality of the image is also strongly affected by the grain. For these reasons the comparison scenes should simulate or duplicate the grain of the scene in question quite

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Approved For Release 2005/12/23 : CIA-RDP79B00314A000500040005-8

Approved For Release 2005/12/23 : CIA-RDP79B00314A000500040005-8

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closely. It is fortunate that the exposure and processing of the material used for most of the work under investigation are quite uniform and thus the grain appears also to be uniform. If, however, other processing is to be considered or wide variations of grain are encountered then the samples must reflect or encompass this variation as well.

Status of Current Work

The term GEMS (Graded Estimated Measuring Samples) has been coined for designating the comparison samples discussed in the foregoing. A first set has been prepared for initial evaluation of the procedure. This set was prepared in the following way:

In making the GEMS in the laboratory we tried to match the following characteristics of the operational photography:

a) Scene - Urban Area

b) Contrast - Medium

c) Scale - 1:325,000

d) Negative Material - SO 132

e) Processing - Full

f) Positive Material - 8430

The Target Panel

We obtained high quality 1:2000 vertical photography, of a large urban area.

Since this photography was made at low altitude without much haze, it had a somewhat larger brightness range than the same scene would have

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Approved For Release 2005/12/23 : CIA-RDP79B00314A000500040005-8

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presented for a high altitude system. To decrease the brightness range the negatives were printed at about 0.6 gamma onto matrix material, producing a somewhat reduced contrast aerial scene.

Two 9 x 9 transparencies were placed side by side on a light panel along with high and low (2:1) contrast resolving power charts, and sensitometric strips.

The Reduction System

This target panel was photographed at an object distance of 163 inches by a camera with a one inch focal length f/2.3 Baltar lens and SO 132 film.

The Production of Various Quality Levels

To produce GEMS of differing quality a through-focus series of exposures was made thus producing pictures in sharp focus as well as others with varying degrees of sharpness.

The Processing

The SO 132 material was processed fully in D-19 to produce a granularity similar to that of fully processed operational material.

The Resolution Levels

The resolutions obtained in the pictures was determined from the images of the 2:1 contrast targets. Negatives with the following resolution levels were selected for the "GEM" mosaic.

1	148 Lines/mm
2	105 Lines/mm
3	66 Lines/mm
4	53 Lines/mm
5	37 Lines/mm
6	26 Lines/mm
7	17 Lines/mm

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Approved For Release 2005/12/23 : CIA-RDP79B00314A000500040005-8

The Positive "GEMS"

Positive transparencies of these "GEMS" were produced by contact printing the negatives onto 8430 positive material. The printing was accomplished with large printing pressure and a point light source.

The positives were developed in D-19 to printing gammas of 1.3 and 1.8. The series of 7 positive GEMS was mounted as a mosaic between 3 $\frac{1}{4}$" x 4" cover glasses for ease in handling. Figure 1 shows a 4X enlargement of the GEM mosaic of the 1.8 gamma positives. Because of low magnification in the reproduction process it is difficult to detect the quality differencies between successive steps.

The Optical Comparison Equipment

To compare the "GEMS" with operational material of unknown quality two monocular microscopes are employed, one for viewing the "GEM" mosaic and the other for the operational material. The fields of view of the two microscopes are brought together by a comparison eyepiece. Figure II shows the equipment. The eyepiece, of the type used for bullet comparisons, presents a circular field of view with a vertical dividing line. On one side of the dividing line the image from the GEM mosaic appears while on the other side is the image of the operational material.

With this simultaneous viewing the judgment of quality differences is simplified. Figure III shows three separate comparisons as seen through the comparison eyepiece. View A shows operational material and a "GEM" that is two steps better in quality. View B shows the same operational material with a "GEM" that is about equal in quality. View C shows the same comparison with a GEM that is two steps poorer in quality than the operational material.

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Approved For Release 2005/12/23 : CIA-RDP79B00314A000500040005-8

Approved For Release 2005/12/23 : CIA-RDP79B00314A000500040005-8

In making the judgment the brightnesses of the two halves of the split field must be approximately the same. To accomplish this a series of neutral density filters has been provided. In addition, a continuously variable transformer, VARIAC, has been supplied for fine adjustment. By using the appropriate neutral density filter and the variable transformer, minor color differences between the appearance of the GEMS and the operational material can be made negligible.

Viewing Magnification

The viewing magnification is critical only in the sense that it must be the same for both microscopes. However, it should also be sufficient to allow the observer to see the fine detail in each picture. For example, the quality steps in Figure 1 do not appear to be very large. This is because insufficient magnification was used in making the reproduction (and, indeed, a loupe will probably not help much either since the print quality is a limiting factor.) Viewed at unit magnification the GEM mosaic shows little or no scale of quality.

Hence the magnification employed for the comparison must be high enough to allow the observer to "see the fine details" in the picture. One consequence of insufficient magnification is that the observer would use factors other than fine detail, such as contrast for finding quality.

The magnification required for reading resolving power charts is normally equal to about $\frac{1}{2}$ the number of lines per millimeter which the picture resolves. More magnification than this decreases the edge gradients seen by the eye and thus makes the picture bigger and less sharp without revealing more significant detail. On the other hand, considerably less magnification, say a factor of 4 smaller than $\frac{1}{2}$ unit per line per millimeter, means that the limitations of the eye itself are beginning to be

Approved For Release 2005/12/23 : CIA-RDP79B00314A000500040005-8

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important. In other words the transfer function of the eye related back through the viewing system to the target material is becoming an appreciable limitation on the reading of detail. For comparing differences one might expect lower power to be required than for reading targets.

In general, because of differences in observers, sometimes a factor of two or more in acuity, the observer should use the lowest power with which he can see all or most of the available detail.

The comparison microscopes are provided with 5X eyepieces 10X eyepieces and 3½X, 10X and 21X objectives. The comparison eyepiece is unit power.

We have found that 50X seems sufficient magnification for judging differences in quality. In many cases 17X appears satisfactory. However, it should be noted again that although differences in quality can be seen with lower power it appears that differences in contrast will affect judgment to a great extent when low power viewing is employed.

With proper magnification small contrast differences could be disregarded. In the end, we compared quality on 76 frames mentioned in the Dirks-Maxey study only with the "GEMS" printed at a γ of 1.8. In a few cases low contrast detail on the operational material made it difficult to obtain a consistent rating value. ★ Checking back on this frame showed it to be extremely low contrast with negligible man-made details for comparison.

In a repeat comparison rating of the 76 frames it was found that the individual readings in the second set differed from those in the first set at most by no more than one scale unit. A distribution of differences is shown in Table I.

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Approved For Release 2005/12/23 : CIA-RDP79B00314A000500040005-8

Approved For Release 2005/12/23 : CIA-RDP79B00314A000500040005-8

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TABLE I

Distribution of Second Readings of 76 Frames with Respect to First Readings:

	Number
Second Reading 1 Unit Higher	7
Second Reading ½ Unit Higher	20
Second Reading Same	24
Second Reading ½ Unit Lower	15
Second Reading 1 Unit Lower	9
Second Reading 1½ Unit Lower	1

In making a comparison judgment the procedure was to record the number of the comparison sample which most nearly approximated in resolution of edges or of fine detail that of the operational material. When it was felt that the operational material was about ½ way between two steps this fact was so recorded with the number of both steps shown. In this way half steps were estimated.

The averaged values of the two readings of the 76 frames from 9056 are tabulated with their frequencies of occurence in Table II.

TABLE II

2:1 Contrast Resolution Levels	No. of Frames
148 Lines/mm	0
105/148 Lines/mm	1
105 Lines/mm	15
66/105 Lines/mm	19

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Approved For Release 2005/12/23 : CIA-RDP79B00314A000500040005-8

Approved For Release 2005/12/23 : CIA-RDP79B00314A000500040005-8

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TABLE II (Cont'd)

66 Lines/mm	13
53/66 Lines/mm	12
53 Lines/mm	12
37/53 Lines/mm	2
37 Lines/mm	1
26/37 Lines/mm	1
26 Lines/mm	0
17/26 Lines/mm	0
17 Lines/mm	0

It is interesting to note that the variation in resolution shown by these figures is only 4 to 1 when one considers the extreme tails of the distribution. And, indeed, it appears that 93% of the data fall within the 2 to 1 resolution range of 53 Lines/mm to 105 Lines/mm.

Now while these readings appear to be indicative of the camera performance from frame to frame, there may be a subtle bias caused by the appearance of the "GEMS" which are used. Many factors could cause such a bias.

1) The original scene, a crowded city area, from which the reduced scale of GEMS were made may have had detail much more closely packed, than most of the detail available for comparison in the operational material.

2) The contrast in the scene we now feel was slightly lower than the average as seen by the operational system.

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Approved For Release 2005/12/23 : CIA-RDP79B00314A000500040005-8

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3) We employed a white light point source for the printing whereas the C/M material is usually printed with a blue, line source.

4) The degradation in GEM quality was produced by throwing a high quality f/2.3 lens out of focus. On the other hand, quality degradation in the C/M system may be produced by thermally induced shifts of focus in a 24 inch f/35 lens or by small vibration or motion errors.

It may be that when the appropriate GEMS have been constructed so that the image characteristics of the GEMS are more nearly similar to the image characteristics of the C/M material there will be even less quality variation evident.

One other fact should be pointed out. All studies so far have been done on the 2nd generation positives. This is one step removed from the system performance as recorded on the original negative and provides possibility for additional quality variation. The system evaluation can be much better accomplished by comparing GEM negatives to the ON's of the C/M missions.

COMPARISON WITH OTHER MEASURES OF IMAGE QUALITY

Reciprocal Edge Spread measurements and Mission Information Potentials are available for 77 frames from Mission 9056. These same frames have been examined by comparison with the first set of GEMS. The results appear in Figures 1 and 2. Because of the dependence of RES values on the average density of the edge the lack of correlation between such results and the GEMS results to be expected. The reason for the low correlation with MIP estimates, however, is not so obvious and a program

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Approved For Release 2005/12/23 : CIA-RDP79B00314A000500040005-8

Approved For Release 2005/12/23 : CIA-RDP79B00314A000500040005-8

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is here suggested to provide input for a better understanding of the usefulness of photographic material of varying quality. This point will be treated further in a subsequent section.

Many frames of the original negatives of Mission 1001 and 9056 have been selected for edge profile measurement. (See section on edge measurements) The limiting resolution of these scenes in the close vicinity of those edges measured has been determined by comparison with GEMS on duplicate positive material. Figure 6 illustrates the degree of correlation between the half widths of the line spread function determined from edge trace and the limiting resolution from GEMS comparison. The correlation is not so strong as might be desired but it is better than the previous two. When the actual transfer function based on the edge trace is used to predict the limiting resolution and this value plotted against the GEMS results a better and more satisfactory correlation appears. Figure 7 is such a plot.

Recommendation

These results are sufficiently encouraging to lead to the recommendation that additional work be done with GEMS. A new set should be prepared with closer steps in resolution and more samples of contrast. This set should be prepared for use on original negative material and the comparison made with such scenes. The additional step of duplication to a positive adds new and undesirable variables.

Evaluation of Usefulness of Material

Once a set of GEMS variable both in resolution and contrast are available in negative form, it seems highly desirable to make positive

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Approved For Release 2005/12/23 : CIA-RDP79B00314A000500040005-8

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prints of these under a variety of printing conditions. Such prints should then be graded on a MIP or any other basis to evaluate the variables of the entire process in their effect on usefulness and value for intelligence purposes. To this end it would seem that a variety of subject material would be desirable.

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